Saimaa University of Applied Sciences
Technology, Lappeenranta
Double Degree Programme in
Civil and Construction Engineering

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Reconstruction of an existing building with one additional storey

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Abstract

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This study intends to analyze possible constructive solutions applied when adding more floors to the existing buildings. The objective was to design the best applicable storey-adding structure, scenarios when strengthening scheme is adopted or not being considered. The work was commissioned by AlfaGasStroy-Servis LLC.

In the study, the emphasis is on the jacket type storey-adding technique when the portal frames on independent foundations are erected around the existing building. The frames joined together to form a structure that bears the load from the superstructure being built. Solutions with reinforced concrete, steel, and timber frame are discussed. In addition, the question of an effective floor system that can be used in the reconstruction is considered.

The estimates are based on existing scientific researches and developments. Calculations are carried out by means of special software using data obtained from the previous designs of the existing building.

As a result of this thesis, it is deduced that the load-bearing performance is weak to withstand the weight of additional structures. The extra storey in the form of a self-bearing system is designed. Materials are chosen considering their effectiveness and construction site conditions, cross-sections of the elements are selected.

Keywords: Storey-adding structure, existing building, additional floor.

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1 Introduction

The existing building's extension by adding storeys has become a reasonable developing activity. The storey-adding concept is well established as an approach to renovate and adapt the older buildings for new needs and requirements.

The case offered in this study is an optimal storey-adding solution for the unfinished two-storey residential building applied with the intent to reconstruct it into the office for the needs of the company. The load-bearing frame was built in 2010 in the Thais Cottage Village (Novosibirsk region) and has masonry as a primary resistance structure.

The interest in the out-of-town office mainly stemmed from the company's operation and maintenance of hazardous production facilities (gas pipelines) activity that requires a technical support centre nearby. In view of building function change, the decision to add a new storey on top and to design a pitched roof was made.

The objective of the thesis is to design the best applicable storey-adding structure on the basis of the available building technical condition assessment data and preliminary studying of the possible variants.

The focus of this work is on the design of an efficient jacket type storey-adding structure for the existing building. The system will comprise portal frames forming a self-bearing structure on an independent foundation. The load will not be transferred to the old structure. The thesis also deals with investigation of the possible structural floor solutions.

The proposed design is intended for the particular constructional project but similar measures could be adopted in meeting the challenges alike. Some calculations, assumptions, and selections were made as a consideration of a proper and realistic design.

The study does not cover the building technical condition assessment and inspection of the existing pile foundation before constructing extra storeys as preliminary made expert examination proves the foundation system capable to carry the additional floors but the load-bearing capacity of the masonry walls is not sufficient, and brickwork strengthening is not effective.

For gaining insight into specific concepts of the building vertical extension, the research and literature review were conducted and similar existing cases were analyzed. The data obtained from the previous designs of the existing building was used in the computational aspects of this work. The structural analysis of the new system was carried out by means of Lira software.

2 Possible structural solutions for the building height increasing

The building height-raising is a very difficult technical problem and requires a deep comparative analysis of possible engineering solutions (Zilberova et al. 2012). Fundamental in the development of the building structural solution is the choice of structural system and material of load-bearing structures, ensuring stability, reliability and safety of operation (Zayats 2013). For these purposes, this paragraph presents the types of structural systems and materials are commonly used when it comes to the vertical extension of the buildings.

2.1 Behaviour of the original structure

The way the superstructure will be implemented depends mainly on the technical condition of the existing building and on the existence of bearing capacity reserves. The following cases are possible here:

- The existing building has the capacity to carry the extension of the building, which means the weight of additional floors is to be supported by the existing building structure.
- The foundation could carry the extension but the surface construction could not and strengthening methods shall be planned to increase its capacity.
- The existing structure has not taken into consideration the building extension and could not transmit the load of additional floors to the

foundation. The extension should be done by means of the self-supporting frame. (Bayan 2016).

- The approach mentioned Slao (1994) when an extension is done also through the new additional frame but with properly executed anchoring to the original structure (Bayan 2016). In this case, the load is partially transferred to the existing building.

Typical examples of the first case are buildings built before the 1950s in Russia (Afanasev & Matveev 2008) and concrete frames used in Finland in apartment blocks built between the 1960s and 1980s (Soikkeli 2016). These buildings have a sufficiently high bearing reserve and can easily bear several additional floors using the light structures. The load-bearing structures of the built-up floors are erected along the outer and inner walls of the existing building over the perimeter strapping belt (girth) as schematically illustrated in Figure 1. The strapping belt contributes to the even load distribution to the reconstructed building and provides spatial rigidity. When using this method, in some cases, the foundation strengthening is necessary (Afanasev & Matveev 2008).

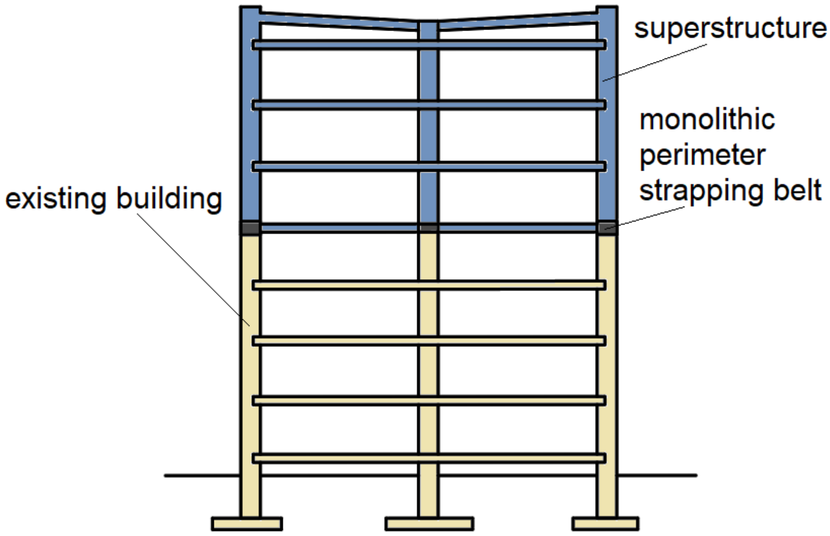


Figure 1. General principle of the superstructure construction on the existing building

This approach is the most common when adding storeys. The samples of its usage are shown below in Figure 2.

Figure 2. Examples of the refurbishment with two-storey superstructure placed on the old building masonry walls: reconstruction in Kiev (on left) (Metal Installation Service n.d.), office building in Frankfurt (Jo Franzke n.d.)

In the second case, when existing structure strengthening is required to carry the extension, engineers resort to element cross-section increasing, additional and duplicate elements installation, unloading the existing load-bearing structure (Kalinin,2004). A couple of examples of the brick structures strengthening are presented at Figure 3.

Figure 3. Brick structures strengthening (Almaz-Rezka. n.d.)

Case 3 appears if the old building has weak walls or foundations, and their strengthening does not have any effect on the additional storey construction (Zilberova et al. 2012). The solution lies in the creation of independent structure to bear the load from the built-up floors (Figure 4). In this case the existing part of the building is isolated and not rigidly related to the new supporting part. It operates as an independent volume (Afanasev & Matveev 2008,p.224).

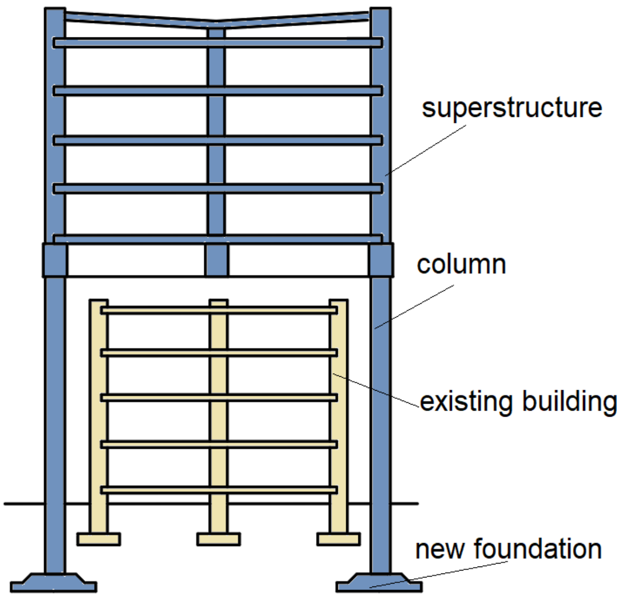


Figure 4. Independent structure to bear the load from the built-up floors

In the last-mentioned case structures of the new external frame are attached to the existing building floor slabs on each floor by means of special elements (Figure 5), for instance, embedded plates in metal frames, ensuring uniform distribution of loads. (Arcelor Mittal & Peiner Träger 2008).

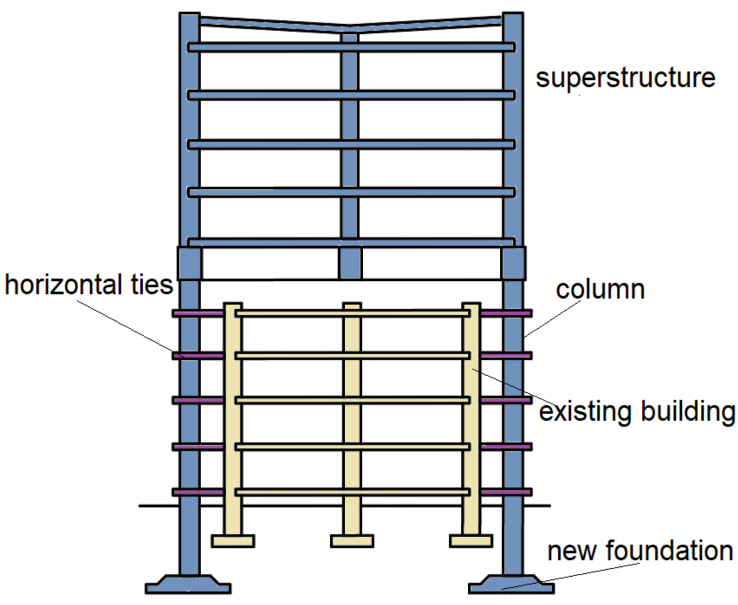


Figure 5. Storey-adding attached structure principle

Thus, taking into account available expert examination results under which the bearing capacity of the masonry walls is not sufficient, and its strengthening is not effective, the third case was adopted for further study.

2.2 Materials used for the frame construction

Evaluation of the reinforced-concrete frame application

The traditional material of load-bearing structures in multi-storey civil construction in Russia is reinforced concrete, which is facilitated by a developed base of the relevant construction industry. Working together steel and concrete make such buildings strong and reliable. Buildings with reinforced concrete frames can be operated for up to 120 years, they are fireproof. However, reinforced concrete structures have a significant weight and large dimensions, and significant energy and financial resources are required to transport such structures to the construction site and lift them to the design position (Bolshakov 2008).

When using reinforced concrete, the add-on structure can be constructed as follows: reinforced concrete shell is erected around the existing building and anchored into its walls, the vertical loads transfer from the superstructure is eliminated by raising the reinforced concrete structure to a level exceeding the level of the existing building roof slabs. The positive aspects of this solution are the formation of the “clamping hoop” by the shell, that increases the stiffness and crack resistance of the existing building. Also such concept allows to distribute the load on the foundation more evenly than in the case of columns, which create a local load transfer to the foundation (which is an unfavorable factor, especially in case of the weak subsoil). (Komarov et al. 2011)

The most common reason for the reinforced concrete use is its lower cost compared to steel, however, according to research conducted by Bolshakov, Razumova, Scherbin (n.d.) metal consumption in reinforced concrete buildings is close to the material inputs in a steel frame of similar height and in some cases even exceeds them. The comparison of reinforced concrete frame structures with metal ones showed a significant advantage of the last-mentioned in terms of weight, loads on additional foundations, the final cost of the implemented design solution per 1 m^2 of the space, as well as in terms of construction time (Zayats 2013).

Thus, the excess metal consumption in steel frames buildings against reinforced concrete ones is not observed and the prevailing in Russia opinion about the alleged inefficiency of the steel structures in civil construction can be considered unreasonable. Moreover, Bolshakov, Razumova, Scherbin (n.d.) classify the use of heavy reinforced concrete to be the main material for storey-adding as the unsuccessful solution, entailing the building mass increase, structure and foundations complexity. The advantages and disadvantages listed above are summarized in Table 1.

Table 1. Advantages and disadvantages of reinforced-concrete frame application

Advantages	Disadvantages
developed industry base	significant weight
strong and reliable structure	large dimensions
durability	significant energy and financial resources
fire resistance	structure and foundations complexity

Evaluation of the steel frame application efficiency

Steel frames are ideal for modern multi-storey multifunctional buildings, including those with an office function (Arcelor Mittal & Peiner Träger 2008).

One of the main qualities of metal structures is a significant speed of manufacture and installation. Elements and assemblies of metal structures are manufactured in the factory and delivered to the construction site in a ready-to-install form (Arcelor Mittal & Peiner Träger 2008).

Low own weight is the major asset of the steel frame. The steel frame buildings are up to 30% lighter than similar reinforced concrete buildings (Arcelor Mittal & Peiner Träger 2008).This feature is especially important for reconstruction when new foundations are required to support add-on structure. In the case of steel structures, foundations can be easily designed to avoid significant influence on existing ones (Gavrilov & Gutenev 2013).

One of the main benefits relative to concrete frames in addition to low weight is the formation of a water-tight building envelope early in the construction process (Arcelor Mittal & Peiner Träger 2008). In our case, when the roof of an existing building is to be disassembled in order for add-on creation, that implying the presence of open structures, this factor is also very significant.

Moreover, advantages of steel construction in operation cannot be considered less significant. Energy efficiency, ease of maintenance, long design life of the building, column-free interior spaces (Arcelor Mittal & Peiner Träger 2008), providing flexibility of architectural and functional zoning significant for modern office building, all of this leads to take a closer look at this solution.

The building with metal structures is an example of sustainable construction, as it meets the criteria of environmental friendliness, efficiency, reliability and safety. The use of the material is highly optimized and waste is virtually eliminated (Sansom & Meijer 2002).

The disadvantages of a steel frame include ineffectiveness of compression resistance due to the loss of the local and overall stability (Bolshakov et al. 2016), which is not a significant disadvantage in our case, when vertical loads are relatively low. In addition, when using steel structures, attention must be paid to corrosion protection (susceptibility to corrosion) and ensuring the required fire resistance (low fire resisting property) (Tusnin & Varaksin 2018).

Metal structures are widely used in Europe in the office building construction. The multifunctional office complexes Bishop Square and Kings Place (London), Le Seguana (Paris), Luxembourg Chamber of Commerce can be mentioned as examples.

In reconstruction projects metal frame is being rolled out globally (Figure 6).

Figure 6. Vertical extension of the office building in Rzeszow (Poland) with steel use (Caroli, 2009)

The advantages and disadvantages of steel frame application are summarized in Table 2.

Table 2. Advantages and disadvantages of steel frame application

Advantages	Disadvantages
significant speed of manufacture and installation	ineffectiveness of compression resistance
low own weight (up to 30% lighter than similar reinforced concrete buildings)	susceptibility to corrosion
insignificant influence on existing foundations	low fire resisting property
formation of a water-tight building envelope early in the construction process	structure and foundations complexity
energy efficiency	
ease of maintenance	
long design life of the building	
flexibility of architectural and functional zoning	
sustainable construction (environmental friendliness, efficiency, waste absence)	

Light steel thin-walled structures (LSTS)

There is a particular interest in the new perspective direction of the skeleton-type construction using light steel profiles when designing add-on structure. The system is a lightweight alternative to hot-rolled steel frame and represents cold rolled C-sections configured to provide portal frame structures of up to 18 m in width (Caroli 2009).

This solution seems to be the most optimal, and sometimes the only possible for use in reconstruction (especially in raising height concept) due to the lowest weight of the structures in relation to all other variants made of heavy metal, wood or glued timber (about 50 kg per meter), manufacturability, low duration and ease of work (BaltProfile 2015). The entire construction process can be carried out without the use of lifting equipment (Association of the Urban Planning Policy and Construction of Moscow 2014).

The examples of lightweight cold rolled sections application are the following illustrations of vertical extension projects in Finland and France shown in Figure 7 and Figure 8 here below.

Figure 7. Adding floor reconstruction of a residential building in Finland using lightweight cold rolled sections (Caroli, 2009)

Figure 8. Add-on structure made of lightweight cold rolled elements (Gardane, France) (Caroli, 2009)

Construction on the basis of light steel structures could be quite successful and effective in solving the task set in this work, as it has undeniable advantages: absence of wet processes, low labour intensity, environmental friendliness, high speed of installation. Such a framework requires a shallow foundation, and shrinkage during the construction and operation is insignificant or completely absent (BaltProfile,2015), and thus solves the main problem with the add-on by using new foundation - a negative impact on existing underground structures and the undesirable involvement of the fenced building in the overall system. (Afanasev & Matveev 2008, p. 225).

Nevertheless, light steel thin-walled structures (LSTS) are quite a complex segment for the Russian metal market (Ignatenko, 2019). According to the Association of the Steel Construction Development (2019), in the world light steel thin-walled structures occupy a significant share in the total residential construction volume (on the average about 15%) and in Russia – the share is hardly noticeable (0,5%), despite of the fact that the use of LSTS has certain advantages. Moreover, in the Methodological guidance approved by the Ministry of Construction of the Russian Federation on January 31, 2019, a direct recommendation not to use LSTS in the construction of multi-storey buildings is given (Ignatenko, 2019).

The problem is the absence of a modern regulatory framework to ensure the competitiveness of the new technology compared to traditional ones. Namely, there are no regulations for the manufacture and regulations for installation and corrosion protection require revision and amendments. Currently, in Russia this technology is still at the development and expert evaluation stage (Nazmeeva 2019).

In view of the foregoing and after examining LSTS market in Novosibirsk region, decision not to use light steel thin-walled structures for the framing in our project has been taken based on two main grounds. The first reason is the lack of technology application experience in Russian construction companies. The second reason for not using this solution was the technological requirement for the bearing vertical members spacing, which should be on average 600 mm according to BaltProfile (2015), up to 3000 mm and less according to Association of the Urban Planning Policy and Construction of Moscow (2014), that does not correspond to the desired architectural solution. The pros and cons of using this technology in the case of study are presented in Table 3.

However, it was decided to apply the concept of LSTS for the construction of building envelope due to the high thermal performance.

Table 3. Advantages and disadvantages of light steel thin-walled structures

Advantages	Disadvantages
the lowest weight of the structures (50 kg per meter)	absence of a modern regulatory framework in Russia
manufacturability	technology is still at the development and expert evaluation stage in Russia
low duration and ease of work	lack of technology application experience in Russian construction companies
lifting equipment is not required	vertical members spacing does not correspond to the desired architectural solution
absence of wet processes	
low labour intensity	
environmental friendliness	
high speed of installation	
shallow foundation	
insignificant shrinkage	

Evaluation of the wood frame application efficiency

The prefabricated wooden frame construction is widely applied in the vertical extension practice. The use of timber for sustainable storey-adding structure is studied in several research works. They show the relevance of timber construction system developed according to the prefabrication principle due to the low own-weight, the shortest assembly time, its very low environmental impact (eco-friendly material), which was attested by a multi-criteria system assessment. The wooden components are adjustable to the different structural grids and static systems of existing buildings. (Dind et al.2018).

Timber was used in the vertical extention of the building without loading the existing one in the reconstruction of a two-storey attic in the Republic of Karelia (Figure 9). The project used transverse three-hinged frames made of LVL timber (Figure 10), which are supported by a steel frame of columns and truss on an independent base, overlapping the existing building. The timber frame is a prefabricated frame with hinged ridge joint and rigid column-to-eaves strut joints assembled with threaded pins. The connections with steel columns are hinged. (Nodwerk 2008)

Figure 9. Reconstruction of a two-storey attic in the Republic of Karelia (Nodwerk 2008)

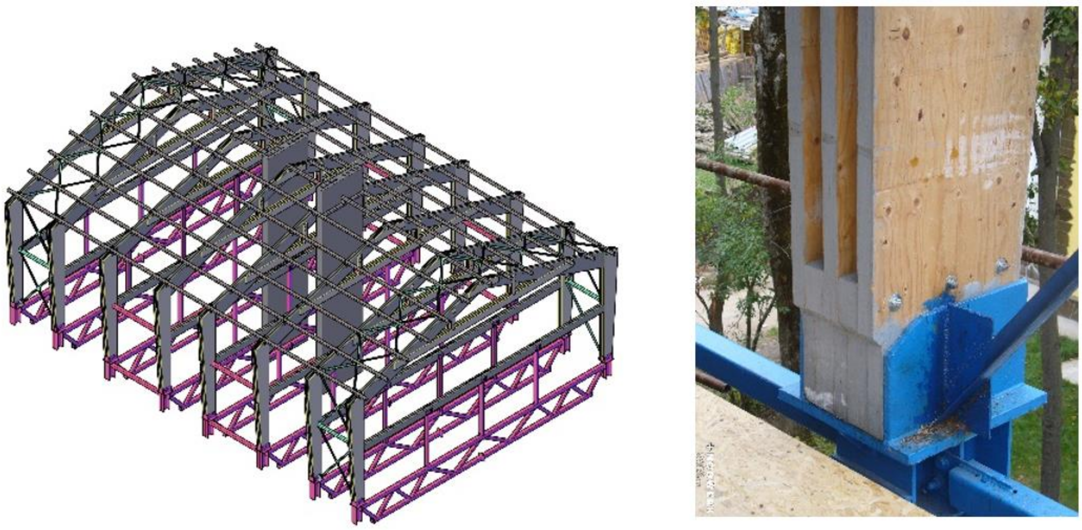


Figure 10. The LVL timber frame structure and hinged connections with steel columns (Nodwerk 2008)

If to use such a solution, the three-hinged frame transfers the thrust to the steel column, this in turn leads to difficulties in the join connection between the timber and steel frames. Also adoption of such an approach in the study case creates the need not only for metal structures supplier but also for wooden structures manufacturer and a contractor familiar with both types of structures. Moreover, the serious obstacle is the poor timber construction industry in the region and the absence of the local material, which entails the long-distance transportation of structures and causes a significant increase in the project cost.

A summary of the design described above appropriateness is presented in Table 4.

Table 4. Advantages and disadvantages of wood frame application

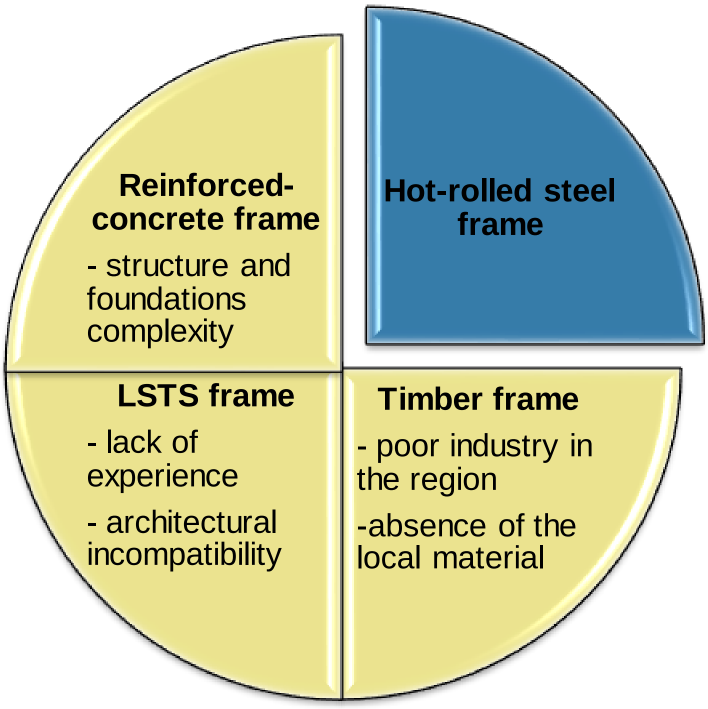
Advantages	Disadvantages
sustainable construction	difficulties in the join connection between the timber and steel frames
low own-weight	need not only for metal structures supplier but also for wooden structures manufacturer and a contractor familiar with both types of structures
the shortest assembly time	poor timber construction industry in the region
very low environmental impact (eco-friendly material)	absence of the local material→long-distance transportation, increase in project cost
adjustable to the different structural grids and static systems of existing buildings	

Conclusion on the frame material adopted in this work

On the basis of the analysis of all the theoretical data studied, consideration of the solutions already used and implemented in the European and Russian practices, it was concluded that the use of steel frame in the storey-adding projects is effective and justified, will make it possible to reduce the cost and accelerate the reconstruction. Steel frame concept viability is supported by scientific researches and by several storey-adding projects of apartment buildings up to 10 floors (Bolshakov et al. 2016). Zayats (2013) comes to similar conclusions.

Selected option and the main reasons for rejecting other solutions are presented in Graph 1.

Graph 1. Selection of the material and its justification



When it is decided to use steel as the main material for the construction of the object, it is necessary to take into account some of the design and construction difficulties. First of all, long preparatory period and organizational difficulties associated with the order of metal, manufacture and transportation to the installation site should be noted. Moreover steel structures located outside the building require corrosion protection, which entails high operating costs for painting, it requires a lot of expenses for fire safety, as steel has no resistance to fire. At high temperatures, steel loses its properties.

Bending is a problem with steel structures. As the length of the steel column increases, the chances of loss of stability also increase, which in our case requires the installation of additional struts and ties that reduce the calculated length.

Steel increases and decreases in volume with temperature change, in turn, the arrangement of temperature-shrinkage seams is an expensive measure, and also considerably complicates the details of external fencing units, which should provide reliable protection from weather conditions and any other environmental influences. In this case, an alternative to the device of temperature-shrinkable joints can be an additional calculation of the frame on the temperature effect.

Façade supporting structures can be more complicated to ensure the thermal requirements, which entails the use of fastening units with eccentricity to the supporting metal structures. Steel elements passing through the insulation require special design and detailing to avoid cold bridges.

Particular attention should be paid to detailing units of building structures, as it influences the required acoustic performance achievement.

Thus the steel frame requires careful design work.

2.3 The detailed study of the jacket type storey-adding technique with use of steel

Underpinning this approach is the installation of additional bored pile foundations along the existing building longitudinal walls on the outer side of the building volume. (Zilberova et al. 2012). It is important to construct foundations with great care and without dynamic loads (Zilberova et al. 2012).

Transverse portal frames are installed on foundations, leaving a gap to the existing building. These frames separated from the old building and jointed together by bracing system, form a rigid basis for the add-on structure. The added floors are also retained by frame module supported by lower portal frame and both structures form the transverse bearing frame. The upper part of these frames is a set of modules placed one on top of the other depending on the number of floors to be built (Figure 11). Typically the module combines several floors. (Bolshakov et al. n.d.)

The distinguishing feature is that due to the independent foundations, the system bears technological and operational loads and thereby completely excludes their transfer to the existing structure. This allows carrying the vertical extension out independently of the bearing capacity of the old foundations and wall envelope. This concept is appropriate for rectangular in a plan or similar shape buildings. Such a solution reduces the restrictions on the additional storeys number. (Afanasev & Matveev 2008, pp. 7-12).

The concept allows to reconstruct with extra floors any low-rise buildings, including those in densely built-up parts of the cities (Bolshakov et al. n.d.).

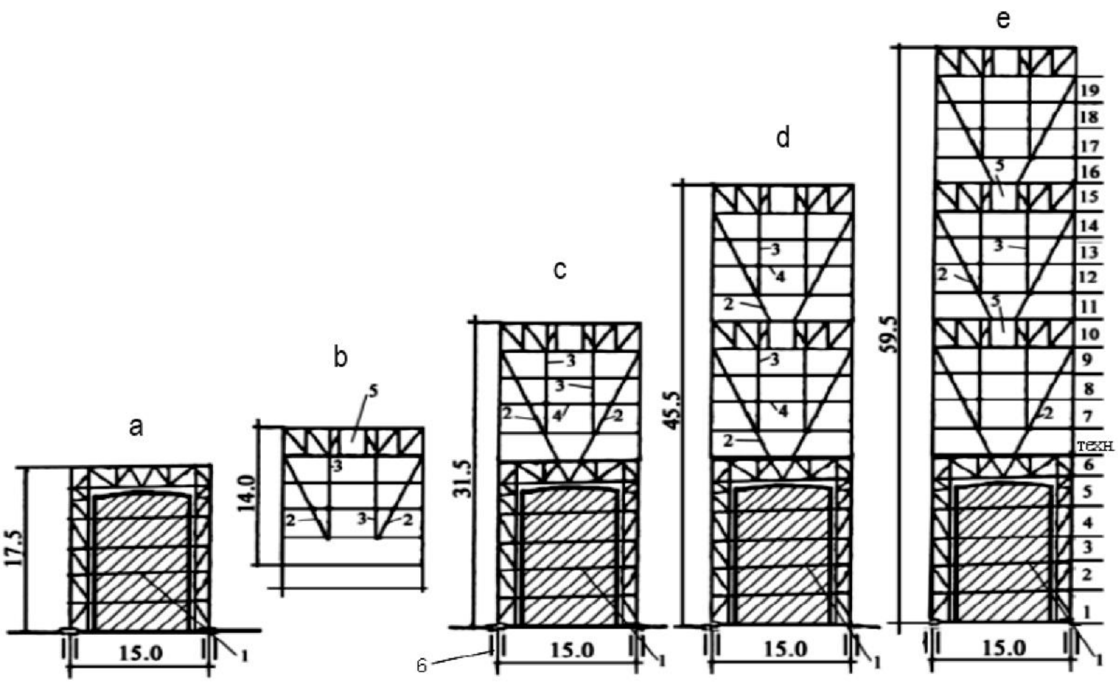


Figure 11. Transverse load-bearing steel frame formation (Bolshakov et al. n.d.) a- lower portal frame, b – frame module, c,d,e– 10,15,20-floors add-on; 1 - existing building, 2 – diagonal bracing, 3 – floor hanger, 4 - interfloor beams, 5 – openings for the passage, 6 - bored piles.

It was Bolshakov V. and Zherbin M. who propose to use steel structures as load-bearing elements, excluding heavy reinforced concrete, while increasing the number of storeys (Zayats 2013). Such a method was called "Flamingo", and its main principle is not to transfer any additional loads to existing structures.

2.4 Examples of the selected technology application in Russia and Europe

The storey-adding technique with an external steel frame, which does not load the existing building structure, was applied during the reconstruction of the LLC Sibkhimproject engineering department building with two additional floors at 24

Komsomolsky prospect, Novosibirsk. Figure 12 shows the reconstruction project developed by Promstroyproekt LLC in 2003, the building at the stage of reconstruction and after it.

Figure 12. Reconstruction of the engineering department building of LLC Sibkhimproject with two additional floors at 24 Komsomolsky prospect, Novosibirsk (Khandozhko, A. n.d)

Below are three more cases of using the same technology: renovation of a residential building on the 19 Osipenko street in Minsk, frame made by Kronverk Metalwork Plant in Moscow and storey-adding structure in Rostov-on-Don (Figure 13).

Figure 13. Examples of Flamingo superstructure performance: residential building in Minsk (Krasovskaya, 2013), frame made by Kronverk Metalwork Plant (n.d.) and storey-adding structure in Rostov-on-Don (Classifieds24. n.d.)

No widespread use of Flamingo storey-adding technology without transferring any loads to an existing building in Europe was found during the study. However, similar methods with the use of metal supports but with partial load transfer are commonly practiced. That is the case of the roof top extension in Boulogne (France) shown in Figure 14. The weight of the extra floors was excessive for the original building, and secondary structure was inserted to support the building extension and transfer the loads to the foundations (Caroli 2009).

Figure 14. Roof extension using hot rolled profiles (Boulogne, Paris), details of the secondary structure junction, extra-column supporting the building extension (Caroli 2009).

3 Investigation of the structural floor solutions for steel frame

The rational floor structure selection is an important challenge while designing the framework (Tusnin & Varaksin 2018). The floor transfers the load to the vertical supporting structures, form horizontal stiffening diaphragm and affects the horizontal movements and vibrations of the whole frame (Tusnin 2015).

This chapter addressed ways in which the floor structure in the steel frame may be implemented.

3.1 Choosing option for the floor system

When choosing a specific flooring solution it is necessary to take into account planning concept, the load on the floor, acoustic performance requirements, availability of certain materials, spans, technical and economic characteristics, manufacture and installation ease (Tusnin 2015). Also it is needed to consider the number of storeys and possible floor-to-floor distance limitations (Arcelor Mittal & Peiner Träger 2008a).

In the construction of multi-storey buildings with a steel frame a wide range of floor systems are available. In the European experience of construction, the most common structural solutions according to Arcelor Mittal & Peiner Träger (2008a) for floors are:

- beams with prefabricated concrete slabs (non-composite (Figure 15a), composite (Figure 15b), integrated beams)
- beams with cast-in-place concrete slabs (non-composite, composite) (Figure 15c)
- beams with cast-in-place concrete slabs with steel decking used as permanent formwork (non-composite, composite, deep composite) (Figure 15d)
- beams with prefabricated composite slab elements (Figure 15e)
- dry floors (light steel with steel decking) (Figure 15f)

Similar design solutions are used and are typical in Russia according to Tusnin (2015).

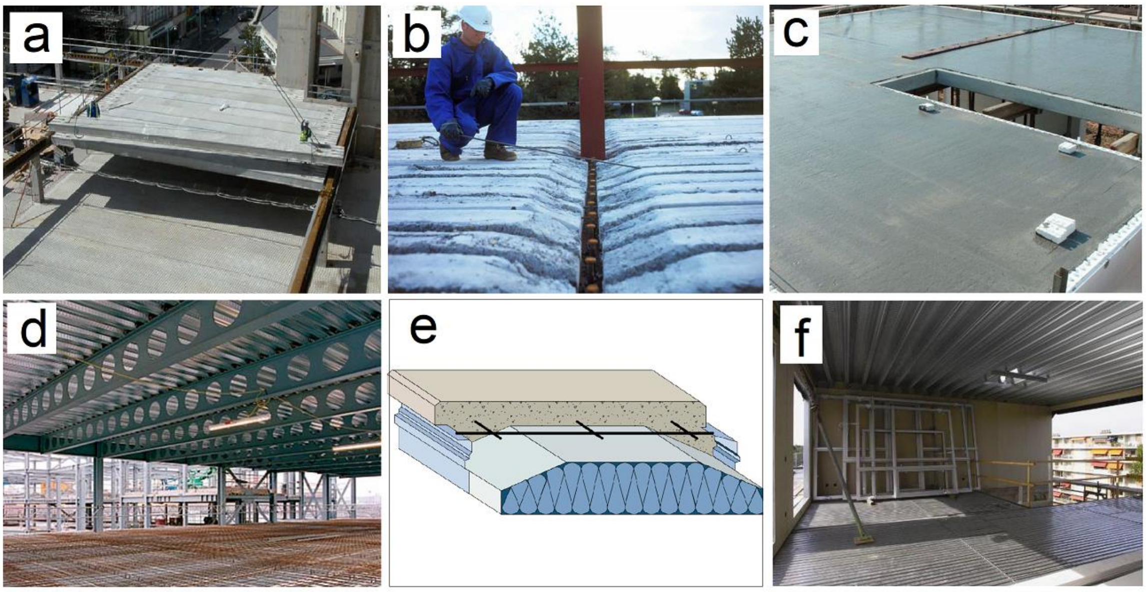


Figure 15. The most common structural floor solutions in metal frames: a – non-composite prefabricated concrete slabs; b – composite prefabricated concrete slabs (Arcelor Mittal & Peiner Träger 2008b); c – cast-in-place concrete slabs; d – cast-in-place concrete slabs with steel decking; e – prefabricated composite slab element; f – dry floor (SCI 2008).

3.2 Floors with prefabricated slabs

The advantages of prefabricated slabs include sufficient fire resistance and good corrosion resistance. Besides, these slabs have high soundproofing properties. There are usually no secondary beams, when using prefabricated slabs. (Tusnin 2015)

There are several ways of using precast concrete slabs in steel-framed building floors (Tusnin 2015).

Non-composite floors with prefabricated slabs

When using non-composite floor, the precast slabs and steel I-beams operate under vertical load independently of each other. This permits when designing the frame to select slabs from the catalogue depending on the operating load without extra calculation and to design the steel beams for the load acting on the loading area taking into account the slab's weight. (Tusnin et al. 2018). The precast units could be hollow core slabs, normally 150-400 mm deep, or solid planks (75-100 mm) and may be used for low rise frames (Arcelor Mittal & Peiner Träger 2008a).

As Tusnin & Varaksin (2018) consider, it is rational to overlap steel frame buildings by means of prefabricated hollow-core slabs in order to ensure the erection using fully completed structural members and the exclusion of wet processes. Full-assembled load-bearing frame increases the speed of construction, provides good technical and economic performance (Gavrilova & Guteneva 2009). Hollow core slabs could cover the span up to 15 m. (Arcelor Mittal & Peiner Träger 2008a).

“Downstand” beams (The slab rests on the top flange of the beam)

This variant is the easiest in terms of technology, which does not require any additional details to install the slabs in the design position. The width of the top flange is sufficient to ensure the slab resting on it (Figure 16). The slabs are attached to the beam on the mortar. The mounting hinges of adjacent slabs are connected by twisted wire or welded. The overall stability of the steel beams is ensured by the stirrup, that are welded to the beam on one ends and the other ends placed in the isolation joints between slabs. After installation the isolation joints are filled with mortar. (Tusnin 2015)

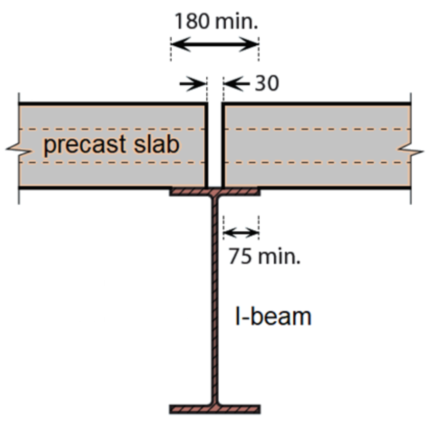


Figure 16. “Downstand” beams

Such a solution is quite economical and allows to cover the spans up to 9 m. (Lindab n.d.) The disadvantage of this option is a large floor-to-floor depth.

The slab rests on the bottom flange of the asymmetrical I-beam

In that case the slab is located within the beam section (Figure 17) that allows to get the floor of the minimum depth (Tusnin 2015), gives freedom of premises planning, increases the fire resistance of steel beams (Tusnin et al. 2018) and, consequently, results in minimizing the fire protection cost - only the bottom flange of the beam must be protected (Lindab n.d.).

The gaps between slabs and beams as well as isolation joints between slabs are filled with cement and sand mortar, the slab hinges are connected to the beams with anchors. (Tusnin et al. 2018)

The solution could be used for covering free spans up to 7.5 m.

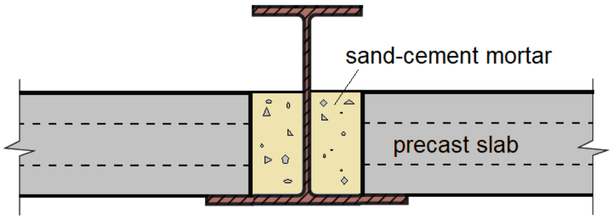


Figure 17. Units sitting on the bottom flange of the asymmetrical I-beam

The slab supported on the “shelf angles”

The precast slabs could be supported on the “shelf” angles bolted or welded to the I-beam (Figure 18). The “shelf” angles section should be enough to ensure adequate bearing of the slab and to make the installation under the top flange possible (Arcelor Mittal & Peiner Träger 2008b).

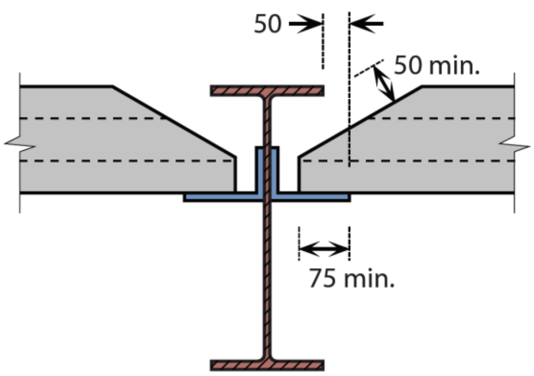


Figure 18. The slab supported on the “shelf angles”

Composite construction with precast slabs

In this design, the precast concrete slabs with concrete infill between its ends and usually with a topping concrete covering rest on the top flange of the beam (Figure 19) forming composite concrete-steel structure (Arcelor Mittal & Peiner Träger 2008b). The steel beam mainly works on the tension, and the concrete slabs, which form the stiffening diaphragm after monolithing the joints, work on compression. This distribution of forces leads to a reduction in the steel beam cross-section height compared to variants where the elements operate independently.

To form a single structure beam and slab are joined together by means of anchors (shear connectors) welded to the top flange of the beam and located in the joint between the slabs and transverse reinforcement placed across the anchors and embedded in the slabs for 600 mm (Tusnin 2015). The anchors and reinforcement transfer the shear force from the steel beam to the concrete. (Arcelor Mittal & Peiner Träger 2008b).

If the development of plastic deformations in the beams is allowed, the slabs can be installed without additional mounting supports. In this case, the beams must be designed to support the weight of the slabs, the concrete infill and the installation load. After the concrete infill gains strength, the structure works as a composite steel-concrete structure, the subsequent increase in load leads to the development of plastic deformation in the beam. (Tusnin 2015).

The precast concrete slabs could be solid planks, normally 70 to100 mm or hollow-core of 150-260 mm depth. Composite construction with precast slab may be used for both low rise and high rise frames (Arcelor Mittal & Peiner Träger 2008b).

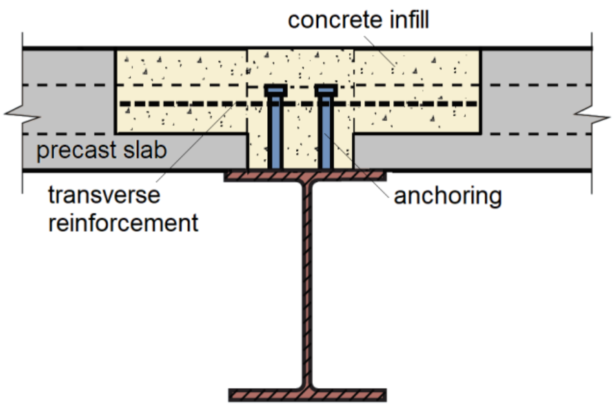


Figure 19. Composite beam with precast slabs

Integrated beams with precast slabs

Prefabricated slabs could be used as a part of integrated beam system, where an additional steel plate is embedded to support the slabs. In that case the beam is located within the floor zone (Figure 20) that allows to form a slim floor.

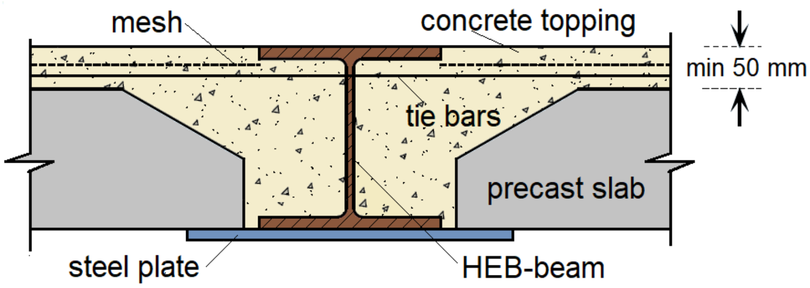


Figure 20. Integrated beam with precast slabs

The steel plate (typically 15-20 mm) is welded to the bottom side of the HEB section and extends by at least 100 mm beyong each side of the flange. The concrete topping with reinforcing tie bars ensures that the elements work together. Both the beam and slab depths depend on each other's spans and are selected in such a way to be compatible in cross section size. The span capability of such structures is up to 9 m.

Integrated beam also could be composite if using welded shear connections. (Arcelor Mittal & Peiner Träger 2008b).

Floors with cast-in-place concrete slabs

In contrast to solid reinforced concrete buildings, where the floor slab forms a single system with beams, in the steel frame buildings beams can work either separately from the slab or together. The solution when beams and slab work separately on the perception of vertical load, is less economical in terms of steel consumption, but due to its simplicity and the well-researched stress-strain state, it is widely used in the design. (Tusnin 2015).

There are two options for the use of solid concrete slabs: the first one, when the inventory formwork is used, fixed on the design mark before the concrete is laid (Figure 21 a, c), and the second, when the steel decking acts as a permanent formwork (Figure 21 b, d).

Options implemented with the use of inventory formwork have a lower (up to 12 kg/m^3) steel consumption and a smooth bottom surface, which facilitates the premise finishing. However, the use of permanent formwork allows to speed up the construction of the cast-in-place slabs, as there is no formwork disassembly operation. (Tusnin 2015).

The thickness of the solid concrete slab is typically from 100 to 200 mm, the beam spacing is 1-4 m (Tusnin 2015) and just as in the case of precast concrete units the structural solutions with slab sitting on the top flange (Figure 21 a, b) and on the bottom flange (Figure 21 c, d) are possible.

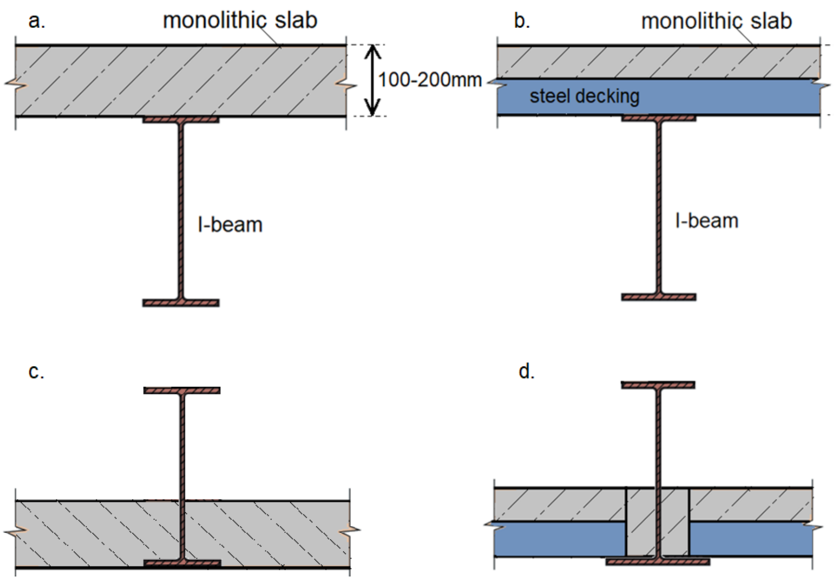


Figure 21. Structural solutions of the non-composite floor with cast-in-place concrete slabs

The operation principle and the method for composite construction with cast-in-place slabs (Figure 22) forming are similar to the variant with precast slabs. In that case the shear connectors are also used to form a single structure as stated earlier. Composite structure allows to reduce the steel consumption and the total floor depth (Tusnin 2015) and could be used for short and medium spans (3-4,5 m unpropped span) (Corus 2002).

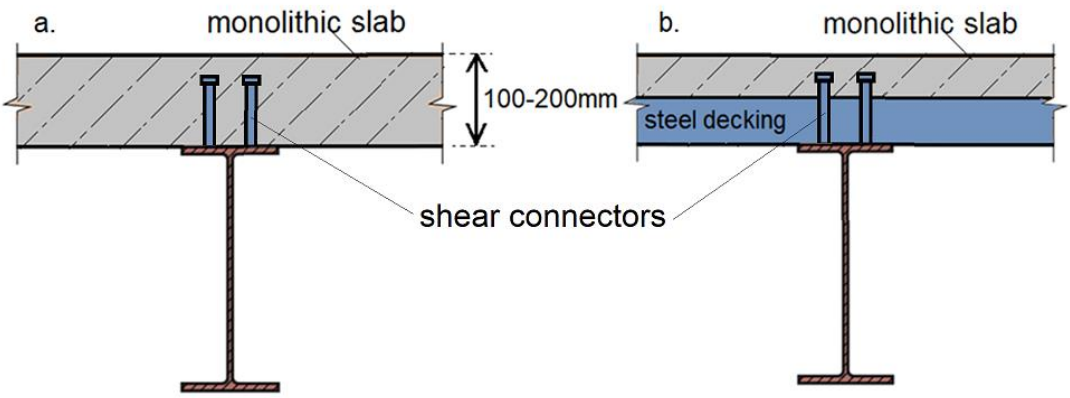


Figure 22. Structural solutions of the composite floor with cast-in-place concrete slabs: a. made with inventory formwork; b. with steel decking as a permanent formwork

Figure 23 shows the general views of the non-composite and composite floor with cast-in-place concrete slabs and steel decking used as permanent formwork. In order to increase the slab fire resistance, distribute localized loads and reduce cracking, the mesh reinforcement (140-200 mm^2/m cross-section area) is installed into the slab. In composite structure it acts as transverse reinforcement around the anchors (Arcelor Mittal & Peiner Träger 2008b).

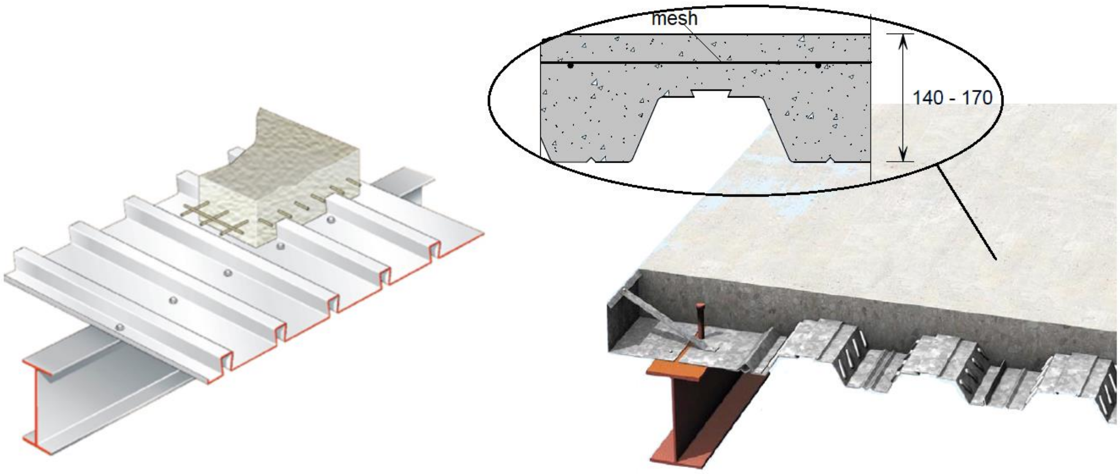


Figure 23. General views of the non-composite (on the left) (Lindab n.d.) and shallow composite (on the right) floor with cast-in-place concrete slabs and steel decking (Arcelor Mittal & Peiner Träger 2008b)

Deep composite floor with steel decking

In such a structure the asymmetric beam with wider lower flange supports the deep deck profiles filled with concrete (Figure 24). Such a floor is slim due to the steel decking is placed within the beam depth. The solution allows to overlap the 6 m span unpropped and up to 9 propped. (Corus 2002)

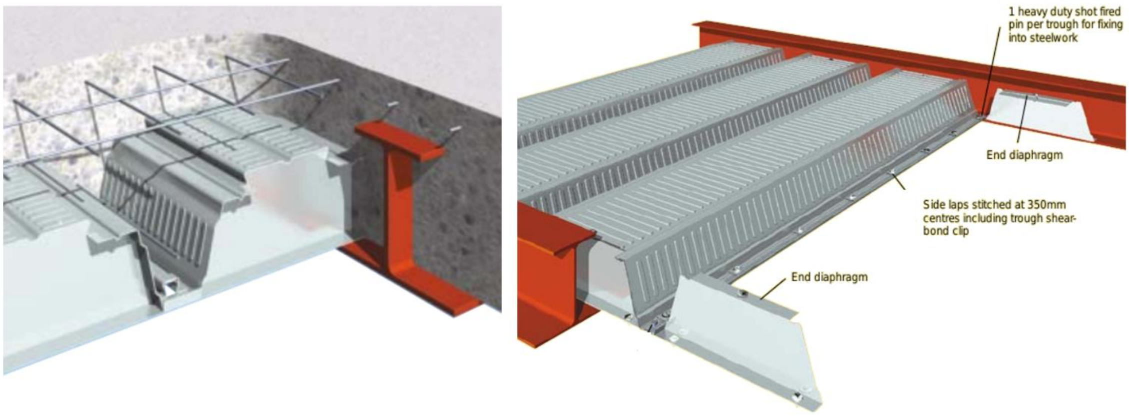


Figure 24. Deep composite floor with steel decking (Corus 2002)

3.3 Floors with prefabricated composite slab elements and dry floors

Prefabricated composite slab

The floor could be formed by a system of beams and prefabricated composite slabs supported by them. Such slabs consist of reinforced concrete, insulation and steel decking (Figure 25). The typical width of slabs is 1,2 m and they cover the span up to 7 m in longitudinal direction (Arcelor Mittal & Peiner Träger 2008 a).

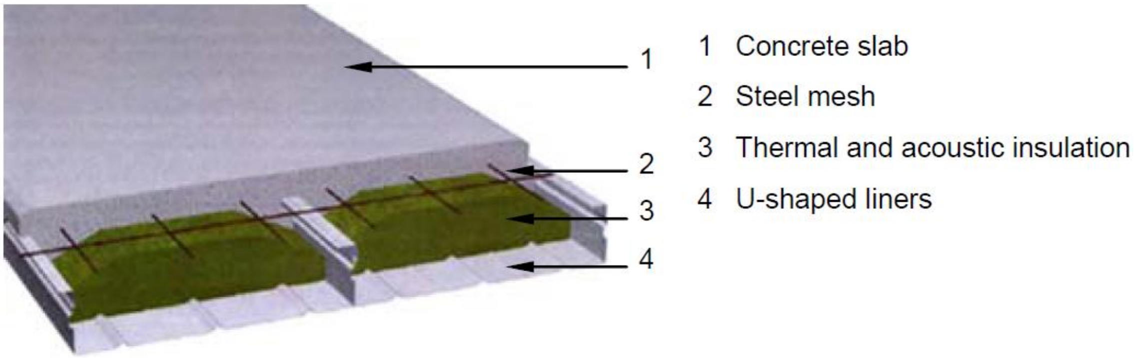


Figure 25. Prefabricated composite floor slab (Arcelor Mittal & Peiner Träger 2008b)

Dry floor

An alternative to massive floors with heavy concrete, are the floors formed by profiled steel sheeting ensuring the load transfer, soundproofing and levelling layers and lightweight concrete inserts (Figure 26).

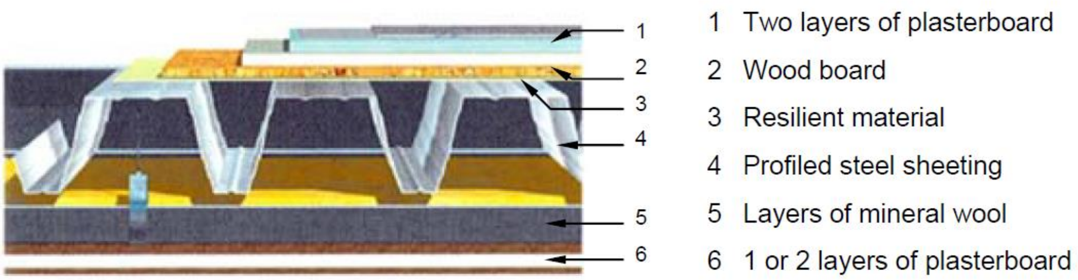


Figure 26. Lightweight dry floor (Arcelor Mittal & Peiner Träger 2008 a)

The main advantages of dry floor solution are lightness, good acoustic and thermal performance. But even more importantly, a full steel frame with floors on steel sheeting is erected up to 40% faster, that allows to start earlier installation of internal engineering networks, enclosing structures, equipment and other work. (Arcelor Mittal & Peiner Träger 2008 a).

3.4 Wooden floors

As the modern construction industry is aimed at energy-efficiency and the use of green construction technologies with sustainable and recyclable materials, of particular interest is the possibility of using timber to create a floor in a building with a steel frame. The combination of these two materials would make the most of their advantages (AISC 2017) The impact of the steel frame superior spanning capabilities and the timber floor lightweight properties consolidation is ultra-light and environmentally-friendly structure with column-free interior space and slim floor system. That would not be economically feasible when using only timber which would either require deep beams to ensure the spans or a tighter column spacing to ensure a slim floor (AISC 2017).

In the course of the work, many cases of a steel frame implemented for the construction both of multi-storey residential and commercial buildings were studied, but no widespread use of wooden floors in such structures has been detected. In the found specialized literature on multi-storey buildings steel frames and commercial building frames, the option of using wooden floors is also not covered. However, there are research works devoted to the possibility of using timber floors as a part of a highly prefabricated steel-timber modern buildings.

A new construction technology with composite steel-CLT timber floor used with braced steel frames was described by Loss et al. (2016). The horizontal prefabricated elements represent the cross-laminated timber panels (CLT) supported by cold-formed steel beams. The panel could be fixed to the cold steel beams in two ways: with mechanical connectors (screws) inserted into Ω-shaped cold-formed steel beams flanges or using U-shaped steel beams pasted by means of epoxy-based resin (Figure 27). The whole building is the equivalent of the classical steel frame with concrete floor structure derived by the traditional concrete slabs replacing with CLT panels. No real examples of the use of such technology was found.

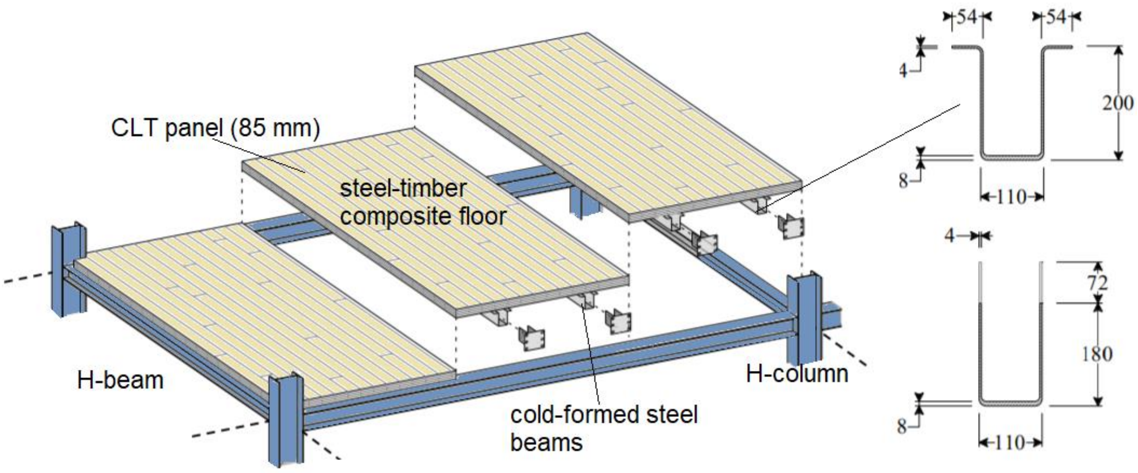


Figure 27. Composite steel-CLT timber floor used with steel frame (Loss et al. 2016)

Another solution was proposed and researched by the American Institute of Steel Construction (2017). In that case the whole system comprises structural steel framing and composite cross-laminated timber (CLT) floor slabs topped with a reinforced concrete layer (Figure 28). The reinforced concrete topping is required for acoustics, durability, fire resistance properties of the floor framing system and also makes the floor system continuous over steel beam supports. The topping concrete slab and the mass-timber planks interaction is provided by shear connectors (screws).

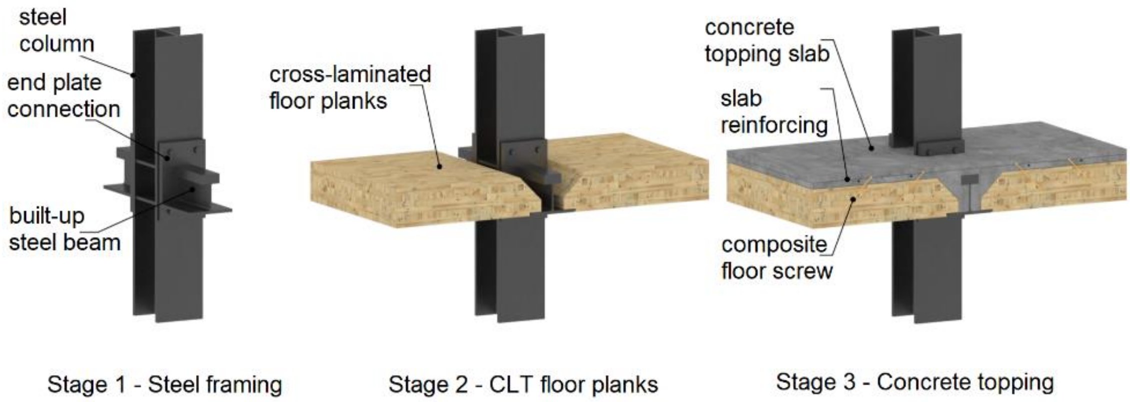


Figure 28. Composite cross-laminated timber (CLT) floor solution (AISC 2017)

The steel beams are asymmetrical in that solution in order to simplify the timber slabs installation on the bottom flanges and are designed with end-plate moment connections. The plate connection is stiff that allow to achieve the required span with a beam depth within the timber slab thickness. (AISC 2017)

The design solutions of the main connections are shown in Figure 29. The CLT slabs braces the steel columns that is ensured by steel plates screwed to the CLT plank and field bolted to the column stiffeners. To each other the CLT elements are fastened with screws.

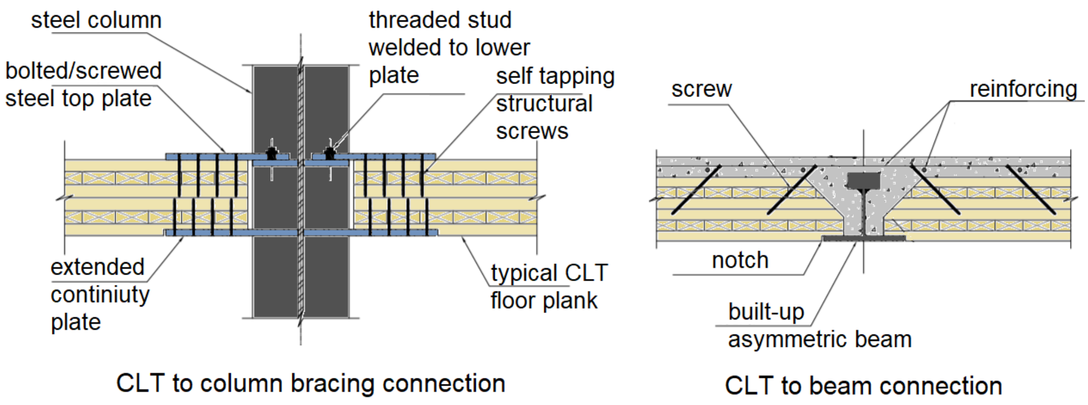


Figure 29. CLT to column and CLT to beam connections

This solution was also developed within the framework of a research in order to determine its feasibility and viability in the building market and has not been implemented yet.

Thus, the use of wooden floors in metal frame building is an interesting and promising direction. There are certain cases of timber floor application in metal frames, but such technology has not been widely disseminated yet. The open question here is the development of reliable connections between the steel and wooden elements which would ensure a flexibility-based materials interaction. The existing connections failure mechanism is not fully studied to guarantee the design durability.

Advantages and disadvantages of timber floor system application in the metal frame structure are presented in Table 5.

Table 5. Advantages and disadvantages of timber floor system

Advantages

- sustainable and recyclable material
- ultra-light solution
- environmentally-friendly structure
- column-free interior space
- slim floor system

Disadvantages

- no widespread use in metal frames (lack of application examples)
- steel-timber connections failure mechanism is not fully studied

3.5 Analysis of all solutions from the perspective of the study case

In our case, it is required to choose the optimal design for overlapping the span with the 14100 mm primary beams distance between the column axes and the length of the secondary beams 7300 mm between the axes.

Following the Arcelor Mittal & Peiner Träger (2008b) recommendations, of all the possible solutions discussed above, two options are taken into consideration regarding our case. They are floor systems with prefabricated concrete slabs and floor with cast-in-place concrete slabs and steel decking.

Notwithstanding the fact that in the context of renovation project when the original architectural facade partitioning must be retained and, consequently, the floor-to-floor height is limited, the integrated beams and slim lightweight steel floors seem to be the most appropriate solutions, due to theirs minimum depth (possible to achieve an overall floor zone of less than 600 mm) and low weight, these options are not considered in view of the maximum span capability of around 9 m. That is not enough in the case of study.

As for the selected solutions the use of reinforced concrete in floor system does not make these variants inappropriate for renovation projects when the self-weight of structures is of great significance since all kinds of steel construction even including concrete floors are lightweight. The typical composite steel-concrete floor weighs 60% less than a reinforced concrete flat slab of the same size (Arcelor Mittal & Peiner Träger 2008b).

Analyzing the experience in metal frame construction can be concluded that among various possible floor system options the most frequently used solution is the one with cast-in-place reinforced concrete slab on the steel decking supported by I-beams. This solution is also common in renovation work because it allows to overlap the spans with unmodulated and non-standardized dimensions (Peshnina & Sinitsina 2017). However, compared to prefabricated units, cast-in-place slabs require a slightly higher consumption of steel and concrete, and they are also more labour intensive (Tusnin 2015).

The main reasons in favour of the second alternative are exclusion of wet processes and ability to provide the single bay by prefabricated hollow core slabs spanning the full building width. Beyond that, such a solution was used to overlap the existing structure. However, the variant with long and massive slabs will lead to great difficulties and costs in the unit's transportation to the construction site and lifting to the height, additionally it requires modulated span parameters.

To conclude these observations, a steel-concrete composite slab on steel profiled decking is proposed as a floor system for the storey-adding structure. That solution allows to overlap the required spans and has a low construction depth in comparison with other possible floor types. Besides, this option is reasoned by un-unified and unmodulated parameters of the new structure.

The biggest issue when choosing such a solution is the high cost of the selected flooring. The structural floor between the existing building and the new super-structure has to be fire resistant, however the fire resistance of the slab is low and requires expensive structural measures to ensure it. In addition, the bearing capacity of the corrugated board, used as a fixed formwork, is not unlimited, which requires a fairly frequent installation of permanent beams in the ceiling or temporary supports (used in concreting).

The installation requires special equipment and trained personnel with sufficient qualifications. Another disadvantage of this type of slab is its low aesthetics, as the beams protrude from the ceiling to the room.

When designing a steel-concrete slab, it is necessary to take into account the dynamic. High dynamic coefficients lead to an increase in the variability of floor coverings, which becomes noticeable for people in the building. A significant role in this case is played by the slab weight and the beam layout plan.

3.6 Examples of the selected floor system application

Composite floor solution with cast-in-place reinforced concrete slab on the steel decking supported by I-beams was implemented in the Bishop's Square office building project in London (Figure 30) for overlapping the spans formed by of 18 m secondary beams and 9 m primary beams. The solution allowed to get the total floor thickness of only 650 mm (Arcelor Mittal & Peiner Träger 2008b).

Figure 30. Bishop's Square office building with composite steel-concrete floor (Arcelor Mittal & Peiner Träger 2008 b)

The 12 m long and 600 mm deep fabricated beams supporting 130 m thick composite slab form a floor system in Kings Place office building (Figure 31).

Figure 31. Kings Place's floor system (Arcelor Mittal & Peiner Träger 2008 b)

4 Designing of the storey-adding structure

4.1 General information on the project

Description of the object of study

The original building represents a two-storey frameless construction with brick load-bearing walls and prefabricated reinforced concrete ceilings (hollow-core slabs) (Figure 32).

Figure 32. Original building: general view and internal space

The foundations type is driven reinforced concrete piles with a 30x30 cm cross section. The cast-in-place pile grating is 550 mm wide. The load-bearing capacity of the 4 m long pile corresponds to the 34.3 tons value. The dimensions of the rectangular building in the plan are 19,8 x 12,5 m. The construction was built in 2010.

The structures, technical condition is generally estimated as serviceable. However, the load-bearing capacity of the masonry walls is not sufficient to carry the additional floors, at the same time the foundation system has sufficient bearing capacity reserves.

The first floor plan is shown in Figure 33. More detailed information on the location as well as drawings giving an idea of the main structures are presented in Appendix 1.

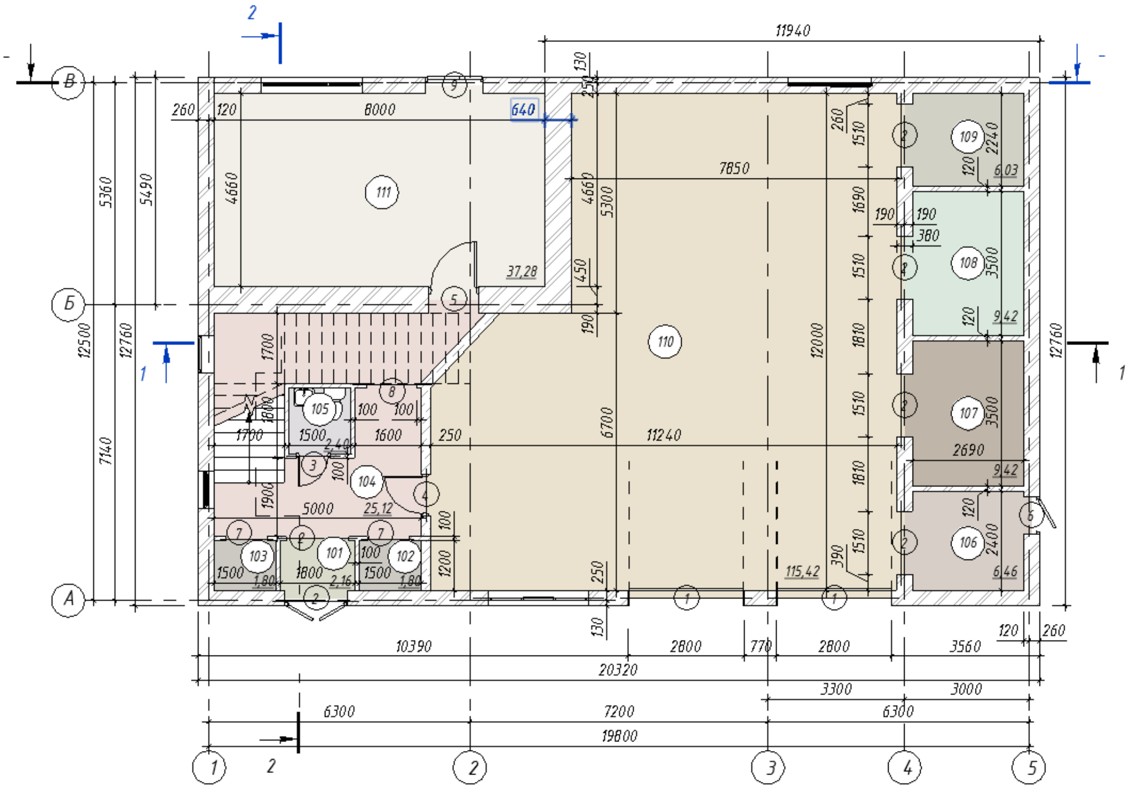


Figure 33. First floor plan

Design tasks

The main purpose of the project is the development of an optimal storey-adding structure. The great difficulty is the old building's inability to bear the vertical expansion load. Among the objectives are also the preservation of the original architectural facade partitioning (floor-to-floor distance requirements), building compliance for the office needs (as, the initial purpose – individual residential building). Besides, the new structures weight must be optimized in order to reduce the impact on the original basement and facilitate the structure transportation and lifting during the installation.

For the project, the additional structure has to remain independent from the original building and also to provide long spans which free the office space. The choice justified in the chapters above was to use a self-bearing steel construction on independent foundations with steel-concrete composite floor.

Client technical requirements

The main physical parameters are specified in Table 6.

Table 6. General physical parameters of the building

Number of people in the building	20
Purpose	Office space. Areas with stationary workplaces
Ratio of useable floor area to total area	90%
Floor-to-floor distance	must be close to 3,52 m
Storey clear distance	3,3 m
Planning module	unmodulated
Fire resistance	II

The building belongs to the normal level of responsibility (KS-2), the reliability factor for liability is assumed to be equal to 1.0 and the estimated service life of at least 50 years in accordance with GOST 27751-2014.

The construction area general characteristics are presented in Table 7.

Table 7. General parameters of the area

Climatic area of construction	1B
Outdoor design temperature of the coldest five-day period	-39ºC
Humidity zone	dry
Seismicity	up to 6 points
Snow area	IV
Wind area	III
Fire resistance	II

Engineering systems requirements

It is assumed horizontal configuration of building services with an arrangement under the floor, above the false ceiling or if possible, within the floor depth.

Loading

The calculation of the load intensity is presented in a tabular form and can be found in Appendix 2. A summary of the loads is given in Tables 8 and 9.

Table 8. Load on the floor

Imposed loading	2,4 kN/m2
Load from partitions	0,6 kN/m2
Ceiling, services, etc	0,5 kN/m2
Floor self-weight:	3,2 kN/m2

Table 9. Climatic loading

Imposed loads on roof	1,716 kN/m2
Snow load	1,44 kN/m2
Wind loading	0,38 kN/m2 (normative value)

4.2 Designing of the transverse frame

Selection of the transverse frame type

There are two possible options: hinged frame with bracing or frame with rigid connections. The frame with rigid column-to-beam connection is applied if there are considerable horizontal forces (Pyatkin et al. 2014). Such a solution is more stiff, but leads to more complex and expensive joints.

Steel-frame multi-storey buildings are generally designed with pinned column-to-beam connections, however for steel structures up to 4 storeys rigid connection could be used (Arcelor Mittal & Peiner Träger 2008 a).

In order to avoid transverse bracing a rigid-jointed continuous frame was designed in the case of study. The moment connection leads to bending resistance and increases stiffness to resist horizontal loads.

The column base was designed to be rigid.

Column grid development

The frame span is assigned based on the existing building plan dimensions considering the possibility of new foundation bases installation. The existing building is 12.5 m x 19.8 m in size, then taking into account the existing foundations size and required setback, as well envisaging wall façade system, the four transverse frames with 14.1 m span between the column axes and with 7.3 m spacing in longitudinal direction.

Bracing scheme development

The spatial stability of the structure is provided by a combinated frame-bracing system. The global stability in transverse direction is ensured by rigid frames, while bracing and secondary beams installed between columns in floor levels provide rigidity in longitudinal direction. The composite floor structure provides transverse and longitudinal horizontal rigidity of the frame. Vertical bracing systems are placed in such a way to avoid obstacles to the free use of interior space. Sufficient rigidity in transverse and longitudinal directions even in the absence of diagonal connections is confirmed by the results of calculation with the use of LIRA software-computing complex.

Selection of the optimum column cross-section

The columns bear vertical loads and transmit them to the base, also perceive wind load.

In this project the column cross-section was selected according to the following criteria:

- architectural preferences of the client
- cost of the rolled steel

- complexity and cost of installation
- simplicity and ease of assembly connections
- additional labor and material costs on a set of measures aimed at ensuring the basic requirements for fire resistance, corrosion protection, etc.
- section and grid sizes

Based on the foregoing characteristics, the section was accepted as it is less expensive than hollow sections.

Principal altitude points

The primary beam bottom is located at the level of 8270 mm, leaving commonly accepted 400 mm above the existing roof bearing structure. This space includes a safety gap for the case of possible beam deflection (Mizumski et al. 2017) and ensures good acoustic insulation and fire resistance (Caroli, 2009).

The required storey clear distance for office buildings according to SNiP 2.08.02-89* Public Buildings and Structures should be between 3 and 3.6 m. For the study case the height is assumed to be 3.3 m as in the original structure.

The beam's structural depth is accepted no more than 1/12 of the maximum span (the distance between columns).

4.3 Static frame calculation

Description of the calculation procedure

Cross-sections selection is made on the basis of analysis of the stress-strain state of the frame elements. Calculations were made on the existing loads and impacts in accordance with the design standards requirements. The frame is designed for the following loads: own weight, slab load, snow and wind. The weight of the floor structures consists of the weight of composite floor system, ceiling and rervices, partitions and imposed load. The normative imposed load on the floor is 2 kPa for the office building according to SP20.13330.2016. The snow load is accepted for the IV snow area, wind load for the III wind area.

The frame design scheme is presented in the form of a finite elemental spatial model and is shown in Figure 34. The work of frame elements (columns, cross-bars) is modeled by universal spatial rod finite elements. The shell elements are used to model floor slabs. To simulate a composite steel-concrete slab, rigid bar inserts are used to link the secondary beams with the slab (Figure 35). The joints between the columns and the roof truss are hinged. The static analysis calculation is made on the basic combinations of loads and influences taking into account the corresponding load combination coefficients.

Static calculation was performed in the Lira SAPR software complex. As a result of the calculation, the maximum design combinations of forces in the cross-sections of columns and beams were obtained, which were used in the cross-sections selection and in the element checking on the first and second groups of limiting states.

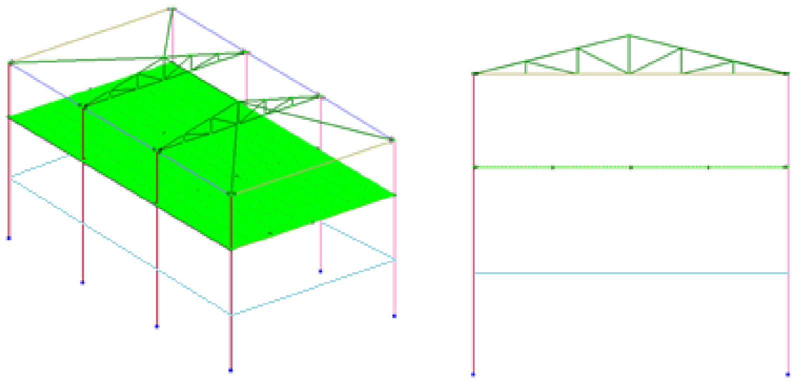


Figure 34. The finite elemental model

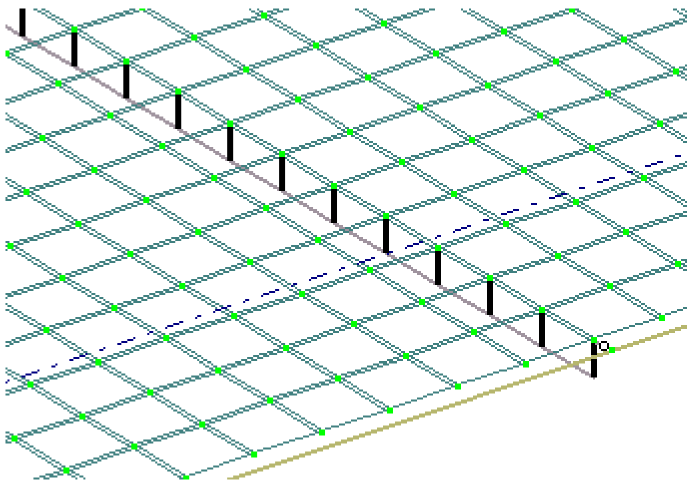


Figure 35. Composite steel-concrete floor simulation in Lira software

Calculation conclusions

For the frame, the transverse distribution of bending moments under the action distributed on the floor slabs is considered. The analysis of the bending moment diagrams showed that the maximum bending moments occur in the primary floor beam. The beam deflections is 0,02029 mm that does not exceed the limit value 0,058 mm for 14.1 m span on aesthetic and psychological requirements (according to SP 20.13330.2016).

To evaluate the frame rigidity under the wind loads action, the calculation of the 14.1 m width building was made. The wind load was assumed for wind area III. According to the calculation results, the top of the column horizontal deflections does not exceed 15 mm, which indicates sufficient rigidity of the frame.

Taking into account the revealed peculiarities of the frame operation, as well as for the purpose of unification, the same columns and beams for all floors were accepted on the basis of the calculations carried out.

5 Main design solutions description

5.1 Bearing structures - the main frame of the building

Columns

The columns are erected in two sections for ease of construction. The bottom part is a two-storey section (9,25 m in length). The upper part is 3 m high. The columns joint is 300 mm above the floor level. All the new columns are on isolated foundations. Cross section accepted –hot rolled I-column 30K1 profile with parallel adgus of flanges according to STO ACHM 20-93, same for both parts (Figure 36). The material is C255 steel.

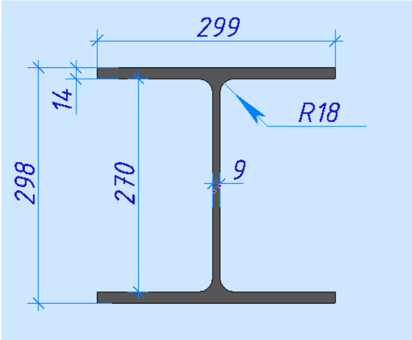


Figure 36. Column cross-section

Beams

Based on the principle of material concentration, the primary beams are placed in the direction of the larger span and support shorter span secondary beams. Long-span 12.1 m primary girders have the 7.3 m distance from each other. Secondary structures have 3.525 m spacing. Together they form a grid of 3.525 x 7.3 m.

Simple beam rolled profiles 30B1 according to STO ACHM 20-93 are used for secondary beams, as the span is relatively small. On the contrary, welded asymmetrical I-beams with 220x10 mm top flange, 360x14 mm bottom flange and 550x10 mm web is used for long span (Figure 37). Some of the long–span elements have individual openings for the services passage. In this way, integration of services within the floor structural depth is achieved. Openings are rectangular in shape (up to 70% of the beam depth) and located in the area of low shear (in the middle third of the span).

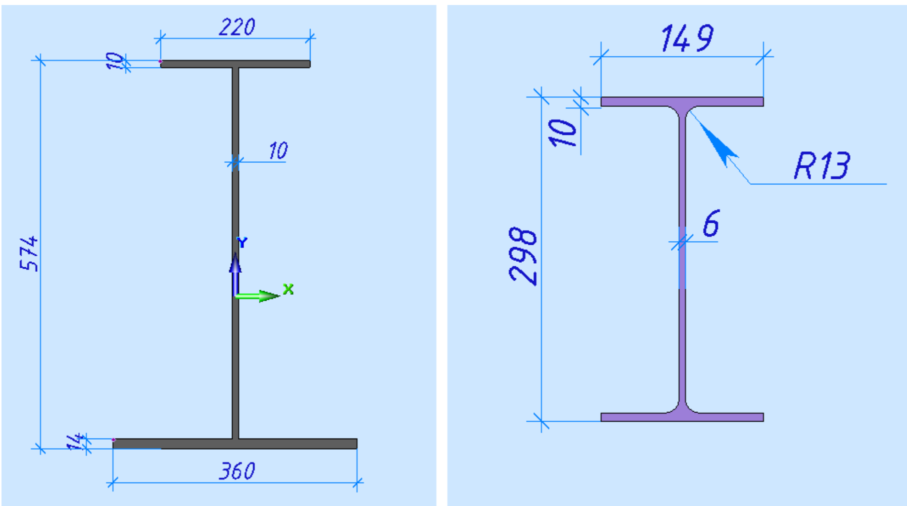


Figure 37. Primary beam (on left) and secondary beam (on right) cross-section

Floor system

A steel-concrete slab with a thin steel profiled decking is used as a floor system.

In order to reduce the thickness and floor weight, the composite work of solid concrete plate with steel beams and the corrugated sheet that serves as a permanent formwork is ensured. This makes it possible to assume a slab thickness of 1/40 of the overlapping span (Shafray 2015). Composite slab is designed as simply supported between primary beams.

CKH 90Z-1000 type sheets according to STO 57398459-002-2011 are accepted as profiled sheeting as they have zigzagging channels that increase the bond of the flooring with the concrete slab. Decking has the 50 mm deep trapezoidal 1,2 mm thick profile as it uses less concrete and spans further than other shape profiles . The normal weight fine-grained concrete with a density of 1800 kg / m3 of class B15 is used. Periodic reinforcement profile A 400 acts as a longitudinal reinforcement. The whole slab depth is 130 mm (Figure 38).

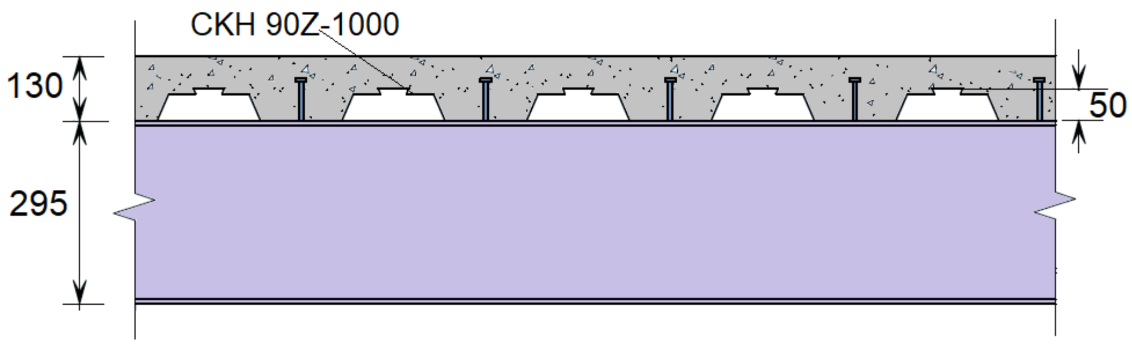


Figure 38. Floor system

Foundations

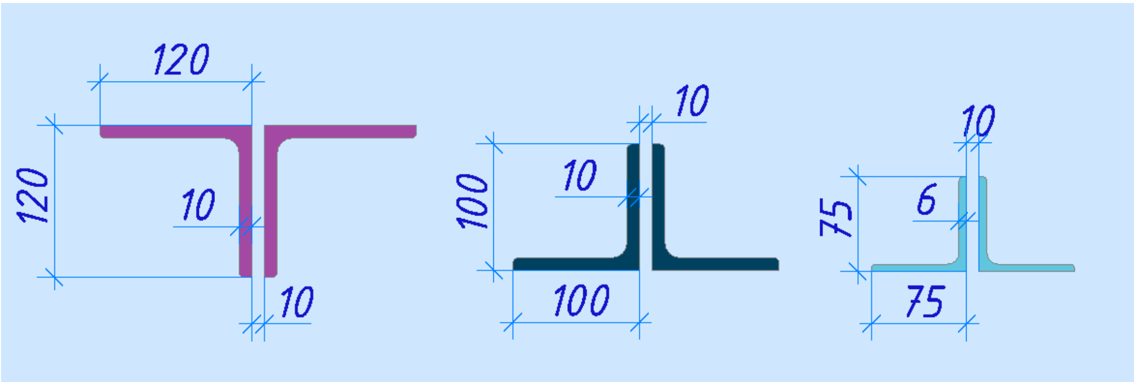
In order to exclude in the process of construction the dynamic impact on the reconstructed building, including the base soil, the additional storey foundations represent prefabricated reinforced concrete piles with a cross-section of 35×35 cm, immersed by the compression method.

Roof structure

Trusses are triangular shape with a slope of 2.5 %. The elements are made of two paired corners of a T-bar cross section (120x120x10, 100x100x10, 75x75x6) (Figure 39). The elements connections are done using shapes and welding. Mounting connections are made on bolts of normal accuracy and on welding. (Figure 40). Steel corrugated sheet coating is attached to rafters and steel purlins.

The roof decking is made of steel profiled galvanized sheet H75-1000-0.9. Ceiling profiled sheet N75-1000-0.9 is attached to the lower belts of trusses and steel girders, a mineral wool insulation is laid above.

The truss-to-column joints are hinged and column-to-column connection is rigid. The steel girders are made of I-beams according to STO ASPM 20-93 №20Ш1. Transverse (wind) covering bracing installed in the building ends is crossed and made of single corners. The geometric invariability of the frame is ensured by the roof and ceiling corrugated sheetings, as well as by the building covering bracings.



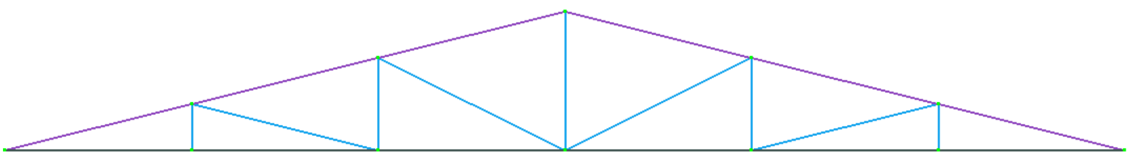


Figure 39. Truss cross-sections: top flange, bottom flange, post and diagonal member cross- section

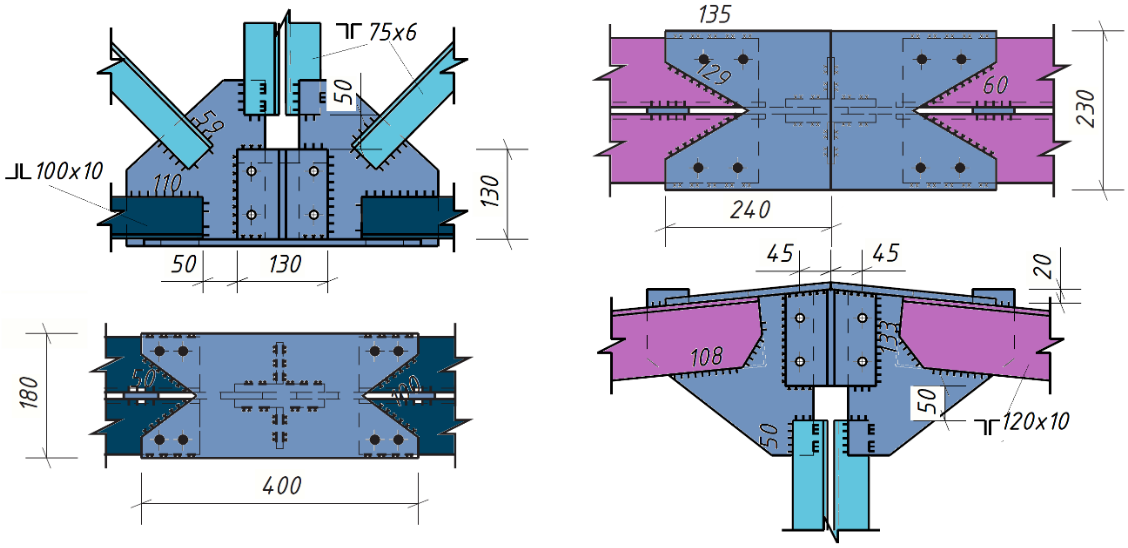


Figure 40. Mounting connections

5.2 Connections

An important factor influencing the adaptability of the frame is the design of its components connections (Tusnin 2015).

All major connections in the sequence below are shown in Figure 41:

- Column to column: rigid, done with splice details
- Column to primary beam: full depth end plate
- Beam-to beam: pinned,
- Column to base: rigid

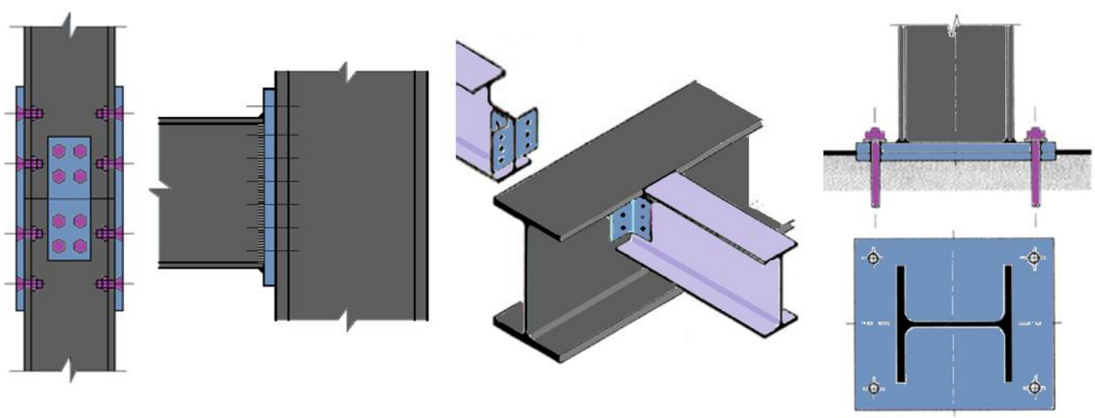


Figure 41. Main connections

5.3 Other structures

Wall envelope structures

Figure 42 shows the wall envelope structures: the left is for the new steel structure and the right is the façade system for the existing building as part of the renovation.

The steel frame exterior walls are lightweight composite facade panels embedded in a steel frame. The brick cladding is self-supporting (less than 12.5 m high). The overall wall thickness is 350 mm including 30 mm external insulated sheating board and 150 mm mineral wool layer. Such structure provides 0.23 W/m^{2}K U-value.

This 650 mm thickness of the old building renovated facade was taken into account when composing the grid of columns of the metal frame.

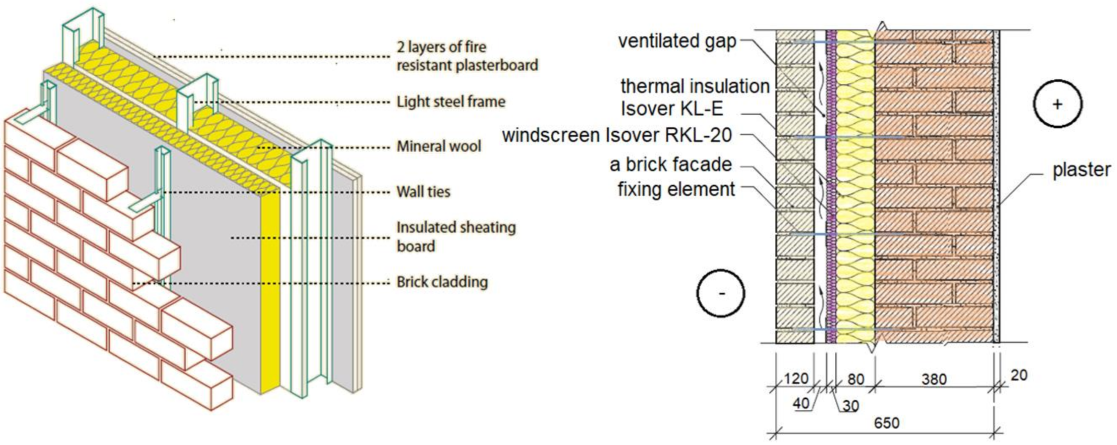


Figure 42. Wall envelope structures: for the steel frame (on left) (SCI 2008), for original building brick wall (on right)

Partitions

The inner walls are a frame of light steel profiles with gypsum sheets. Soundproofing (from structural noise) is provided by gluing the profile from EPDM-rubber or tubular hollow bundle. Sound insulation (from air noise) is achieved by tight fitting the profile to the walls and floor and filling the cavities in the wall structure. Partitions are placed on floor slabs.

5.4 Metal consumption and approximate cost analysis

The total steel consumption for the frame of the designed building is approximately 58.38 m.

Building a storey-adding structure with an area of 308.79 m2 (additional floor area) costs, excluding the cost of existing building reconstruction, taking into account the prices prevailing in Novosibirsk as of November 10, 2019, will approximately amount to 8.636 million rubles (includes material and installation costs).

6 Conclusion

This work addressed the most rational ways in which a building may be vertically extended to create a new space. The achieved result of the work is the developed at first approximation optimal design solution for the additional storey structure for a frameless low-rise building with brick walls.

In order to work out the storey-adding construction in the framework of the renovation project, the study was conducted in the following directions. Firstly, the possible structural solutions for the building height increasing were analyzed. The selected structural method was underpined by considering the similar projects of buildings reconstruction in Russia and abroad.

Secondly, while investigating the vertical extension techniques and experience with the intent to define an optimum solution for the case of study, it became necessary to analyze also the structural floor options for the steel frame. All the data on the possible approaches, which were found in the specialized literature, publications or presented by manufacturers and which were already applied on the objects were thoroughly analysed from the point of view of efficiency, economy and labor input. The most commonly used and reasonable design solution was accepted.

A study was also carried out to collect information for European experience in steel frame construction and to learn about new steel-intensive renovation techniques as such industry has a highly developed base there.

For the case in question about the existing 2-storey building in the Tais Cottage Village in Novosibirsk region a steel-frame storey-adding structure made of hot-rolled profile elements was developed using the Flamingo system.

The applied design solutions allowed to increase the number of storeys of the steel frame to 3 floors. In this framework, the overlap represents a steel-concrete composite slab on steel profiled decking. The supporting frame consists of columns, beams and bracing. Such a combinated frame-bracing system provides the spatial stability of the structure.

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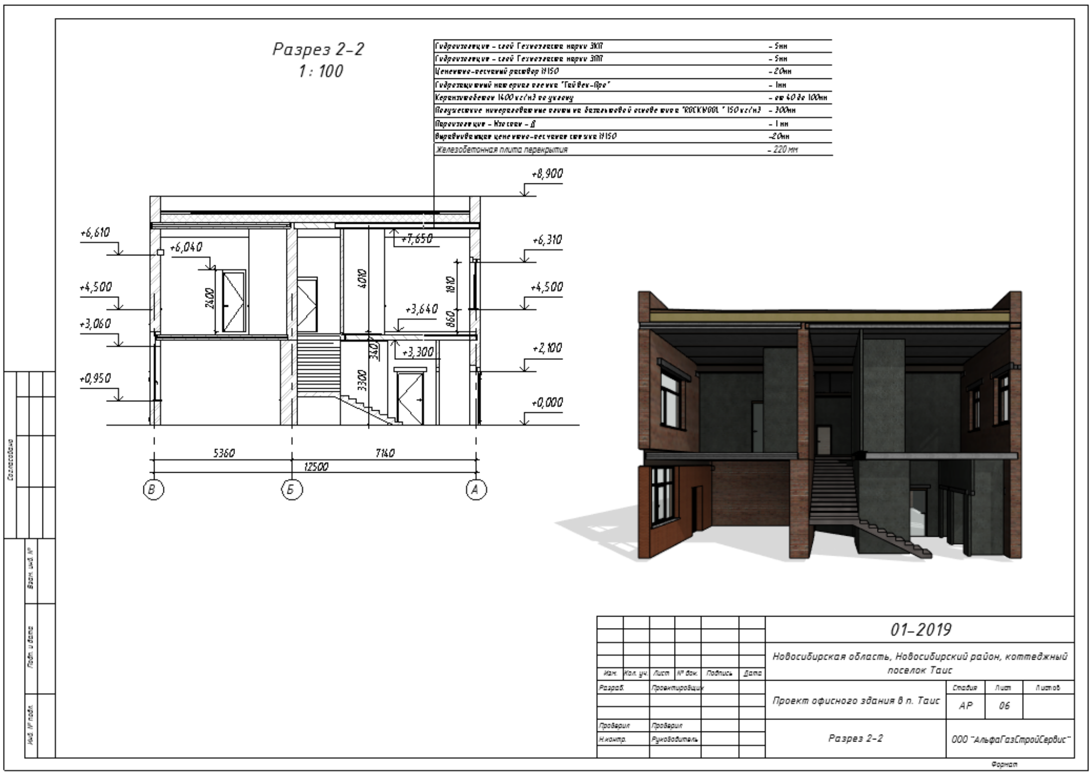
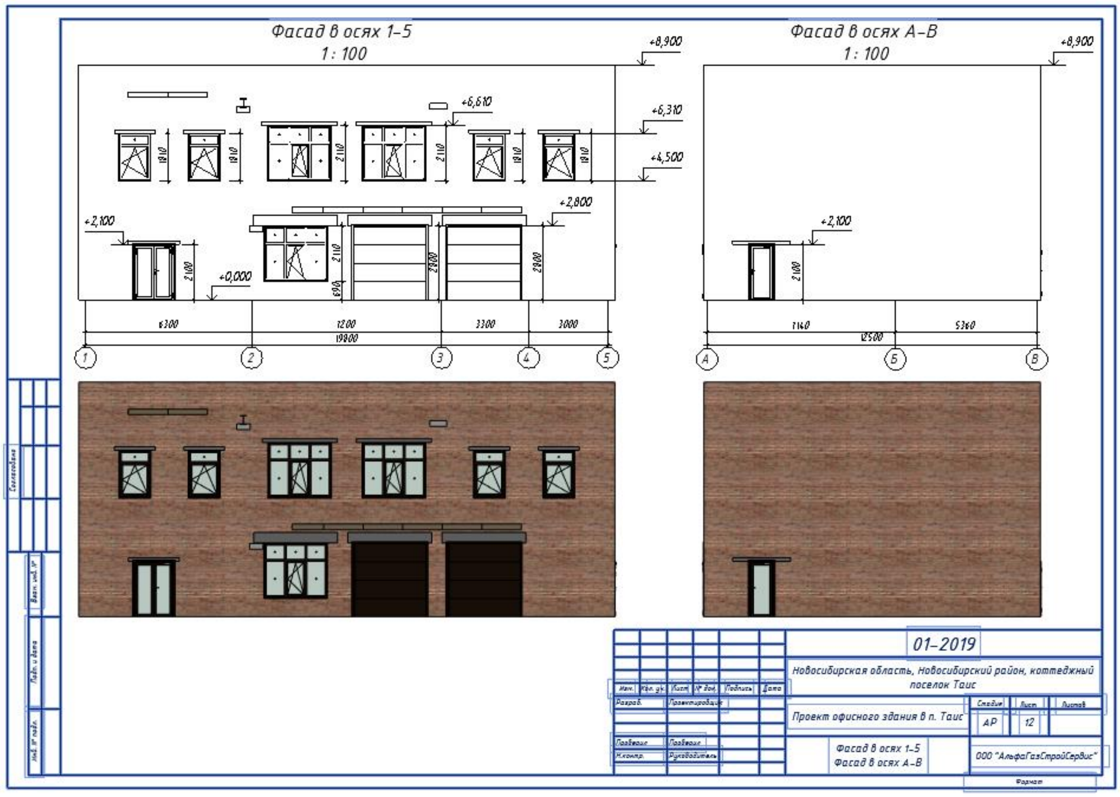
Appendices

Appendix 1. Drawings in Revit





Схемы расположения плит перекрытия 1-го этажа на отметке 3,300
1 : 100

01-2019

Новосибирская область, Новосибирский район, коттеджный поселок Таис

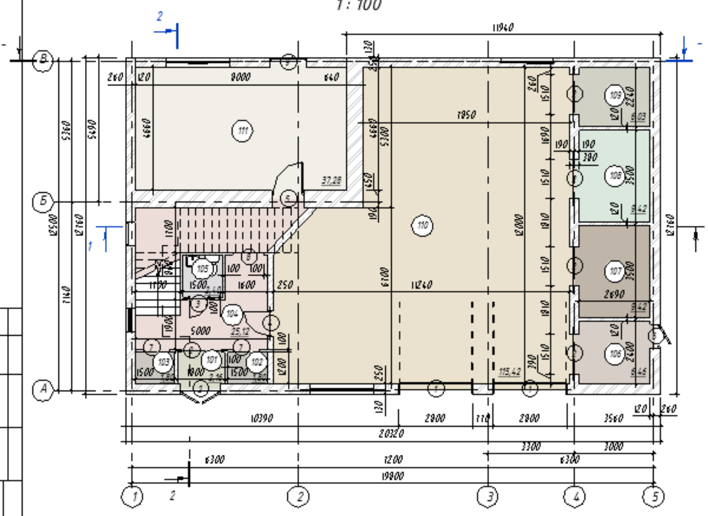
Проект офисного здания в п. Таис

Схемы расположения плит перекрытия 1-го этажа на отметке 3,300

Стадия	Лист	Листов
КР	06 КР	

ООО "АльфаГазСтройСервис"

План на отметке 0,000
1 : 100



Экспликация помещений

№ пом.	Наименование	Площадь, м²	Кат. пом.
101	Тамбур	2,16	
102	Гардеробная	1,80	
103	Гардеробная	1,80	
104	Холл	25,12	
105	Санузел	2,40	
106	Генераторная	6,46	
107	Газовая котельная	9,42	
108	Пеллетная котельная	9,42	
109	Пеллетная	6,03	
110	Гараж	115,42	
111	Веранда	37,28	
Общая площадь		217,28	

Ведомость проемов в кладке

Поз.	Размер проема
1	2800х2800
2	1510х2100
3	910х2100
4	1010х2100
5	1210х2100
6	910х2100
7	1000х2100
8	1200х2100
9	1380х2100

01-2019

Новосибирская область, Новосибирский район, коттеджный поселок Таис

Проект офисного здания в п. Таис

План на отметке 0,000

Стадия	Лист	Листов
АР	02	

ООО "АльфаГазСтройСервис"

Appendix 2. Visualization of the new project